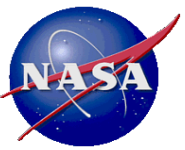


The State of Play US Space Systems Competitiveness

Prices, Productivity, and Other Measures of
Launchers & Spacecraft

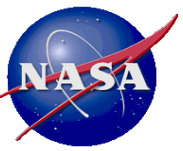
Edgar Zapata
NASA Kennedy Space Center

*Presentation to the Future In-Space Operations (FISO) Seminar
October 11, 2017*



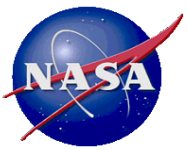
Purpose

- Collects (only) **PUBLIC** space systems cost and related data –flight rate, payload mass, etc.
 - Compile **public** data - contract announcements, budget docs, etc.
 - Separate **non-recurring and recurring**
 - **Minimal data processing**; if adjustments, only for apples to apples
 - Inflation to current year dollars, to same orbit, same mass metric, etc.
 - **Provide context**, compare across systems, graph, visualize
 - Focus on US space systems **competitiveness** (it's not all just costs)
 - **Keep fresh**
 - Update as new data is published, as launches occur, etc.
 - Focus on **recent data**, indicative of the near future



Purpose

Collect
Measure
Inform

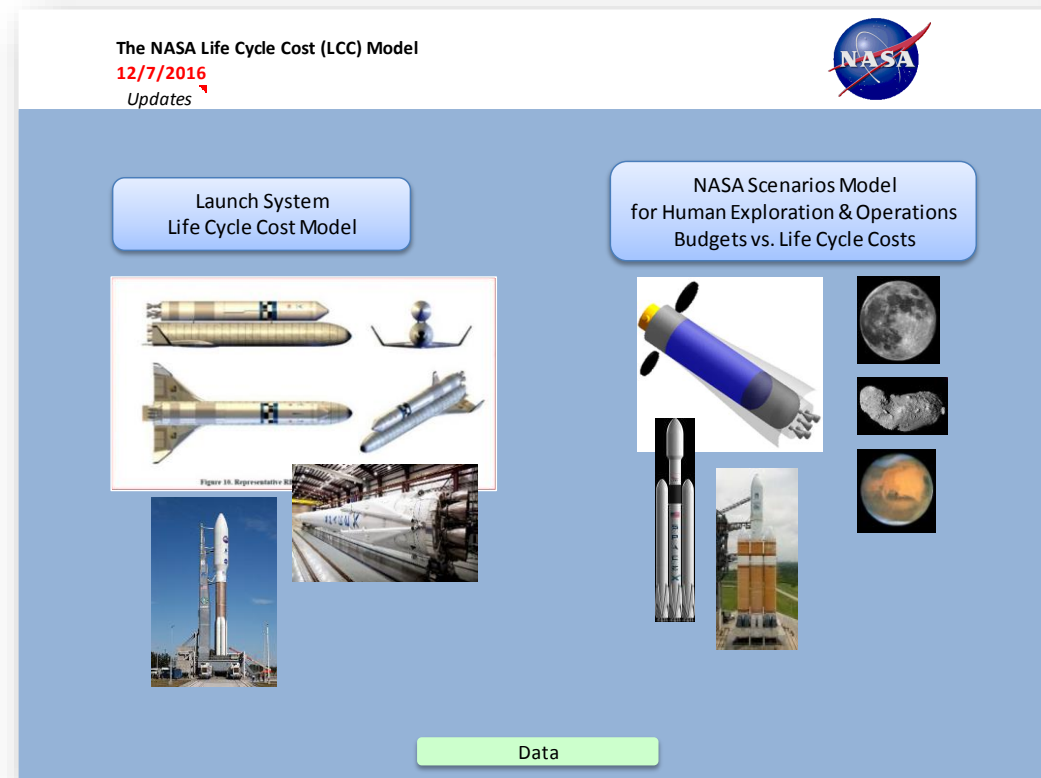


Caveats & Terminology

- The “price” to a customer is the procurement or contract “cost” to NASA, DoD, NRO, private sector, etc.
 - But total costs would include other internal program/project management costs – in a government agency, personnel and other costs
 - The data ahead are almost all flavors of this (NOT the “costs” inside a company or agency *before this or that are added, etc.*)
 - Among many other “asterisks”
- Uncertainties - inevitable; data refinement - continuous
 - Minimally processed data BUT-
 - Anecdotal evidence some launch pricing actually runs much higher in the end than publicly announced or advertised (Russia/Proton, etc.)
 - Some public data is processed more – due to different contract phases, multiple partners, not yet complete, age of the data, etc. (SLS, Orion, Commercial Crew, Apollo, etc.)

Source Data

- Source data for this report is available in the Life Cycle Cost (LCC) Model
- Data sheets are available upon request to NASA, government, government contractors or for peer/collaborative purposes
- Contact edgar.zapata-1@nasa.gov





Source Data

Example Data Sheet

Nominal or
Inflated

Document public
source, pp., doc, etc.

Document and justify
adjustments
(like “no EUS”)

NON-RECURRING COSTS

Sources: re. Notes Below

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
\$M Real Year	\$ 839.2	\$ 479.5	\$ 889.5	\$ 1,387.2	\$ 1,640.0	\$ 1,196.0	\$ 1,200.0	\$ 1,113.8	\$ 1,197.0	\$ 1,194.0	\$ 1,270.0	\$ 1,350.0	\$ 1,119.9	\$ 1,123.3	\$ 1,135.1	\$ 1,153.3	\$ 1,175.8	\$ 1,198.7	
Inflation adjustment to 2017 per NASA																			
Inflation Index	1.276	1.244	1.213	1.185	1.160	1.138	1.127	1.105	1.080	1.066	1.036	1.000	1.025	1.051	1.078	1.104	1.130	1.157	
\$M 2017S	\$ 1,071.0	\$ 596.7	\$ 1,078.6	\$ 1,643.8	\$ 1,902.5	\$ 1,361.5	\$ 1,352.7	\$ 1,230.4	\$ 1,292.4	\$ 1,272.4	\$ 1,315.6	\$ 1,350.0	\$ 1,092.1	\$ 1,068.0	\$ 1,053.3	\$ 1,044.7	\$ 1,040.3	\$ 1,035.7	
Sum Procurement & Gov't 2006 to here in RT \$												\$ 12,406							
Sum Procurement & Gov't 2006 to here in 2017S												\$ 14,117							
Sum Procurement \$ ONLY 2006 to here in 2017S												\$ 12,605							
Sum Procurement \$ ONLY 2017 to here in 2017S												\$ 6,862							
Total Orion Development Procurement ONLY \$M in 2017S												\$ 19,468							

From above data

Cx Era 2006 to 2010 and 2011 \$M nom.

\$ 5,235

\$ 6,431.4

Orion nom. year 2012-2021 \$M

\$ 11,857

< Compare -> Apx. Program LCC per GAO Mar. 2016

See GAO-16-3095P

Orion nom. year 2011-2021

\$ 13,051

\$ 11,284 is ok

Total nom. \$

\$ 20,663

Total in 2017S

\$ 21,802

This data sheet gathers all the PUBLIC NASA budget data for this program and indicates all the source documents.

The actual costs to date were the sum of the budgets through the date indicated, usually up to the current year, with the numbers after being the planned budgets from the same documents.

Minor adjustments include separating out Government program/project management, civil servants et al, vs. the contractor "procurement" dollars, as well as creating a new line in current year dollar management using the official NASA inflation indices.

NOTE! "Actuals": PUBLIC budget data, actual costs, appear in NASA budget documents a year or more after the budget year indicated. For example, the "Actual" 2008 budget data is found in the 2010 NASA budget request.

The OFFICIAL RECORD INDICATES:

This is the data for Orion, before 2011 (aka CEV, MPCV) in Real Year \$M:

2006-\$839.2 (re 2008 budget doc, 168652main_NASA_FY08_Budget_Request.pdf, pg. 308)

2007-\$479.5 (re 2009 budget doc, 210019main_NASA_FY09_Budget_Estimates.pdf, pg. 6)

2008-\$889.5 (actual", re 2010 budget doc, 345225main_fy_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)

+dist. PI&O: add 40%, i.e., 2007-\$714.5

2009-\$889.5 (actual", re 2010 budget doc, 345225main_fy_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)

+dist. PI&O: add 32%, i.e., 2008-\$1174.1

2009-\$1,387.2 ("enacted", not "actual" - re 2010 budget doc, 345225main_fy_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)

+dist. PI&O: add 26%, i.e., 2009-\$1,747.9

2010-\$1,383.5 ("request" not actual, - re 2010 budget doc, 345225main_fy_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)

+dist. PI&O: 2010 -\$1,640

2011-\$1,196.0 (re 2013 budget doc, 622655main_FY13_NASA_Budget_Estimates.pdf, pg. 4)

2012-\$1,200.0 (re 2014 budget doc, 740512main_FY2014_CJ for Online.pdf, pg. 8)

2013-\$1,113.8 (re 2015 budget doc, 508_2015_Budget_Estimates.pdf, pg. 5)

2014-\$1,197.0 ("actual", - re NASA_FY_2016_Budget_Estimates.pdf, pg. 5 = BUD-5)

2015-\$1,194.0 (ESTIMATED / TENTATIVE - NASA_FY_2016_Budget_Estimates.pdf)

(51,350.2 "operating plan" value per "fy_2017_Budget_Estimates.pdf")

Then, inflation adjustments to 2017S, and removing 12% (government management). The model adds this back in separately, the "Industry/procurement" portion of this would be apx. \$12.605M spent on Orion before 2017 in 2017S.

2016-2022

1. Build of year by year nominal budget data:

2016 = \$ 1,270M

p. 182, 2016-CPRT-114-HPRT-RU00-SAHR2029-AMNT1final.pdf

2017 - from FY 2017 budget deal - 2017 i-fy 17 wrapup budget deal -CPRT-115-HPRT-RU00-SAHR244-AMNT.pdf

-\$51,350M

Also see sheet "Data-NASA Budget" for detail

2018 - 2021 -> p. BUD-4, fy_2017_budget_estimates.pdf

NOTE! Senate version 2017 = \$1,300M (not \$1,270M)

http://spacenews.com/senate-bill-cuts-other-nasa-programs-to-fund-sls-and-orion/

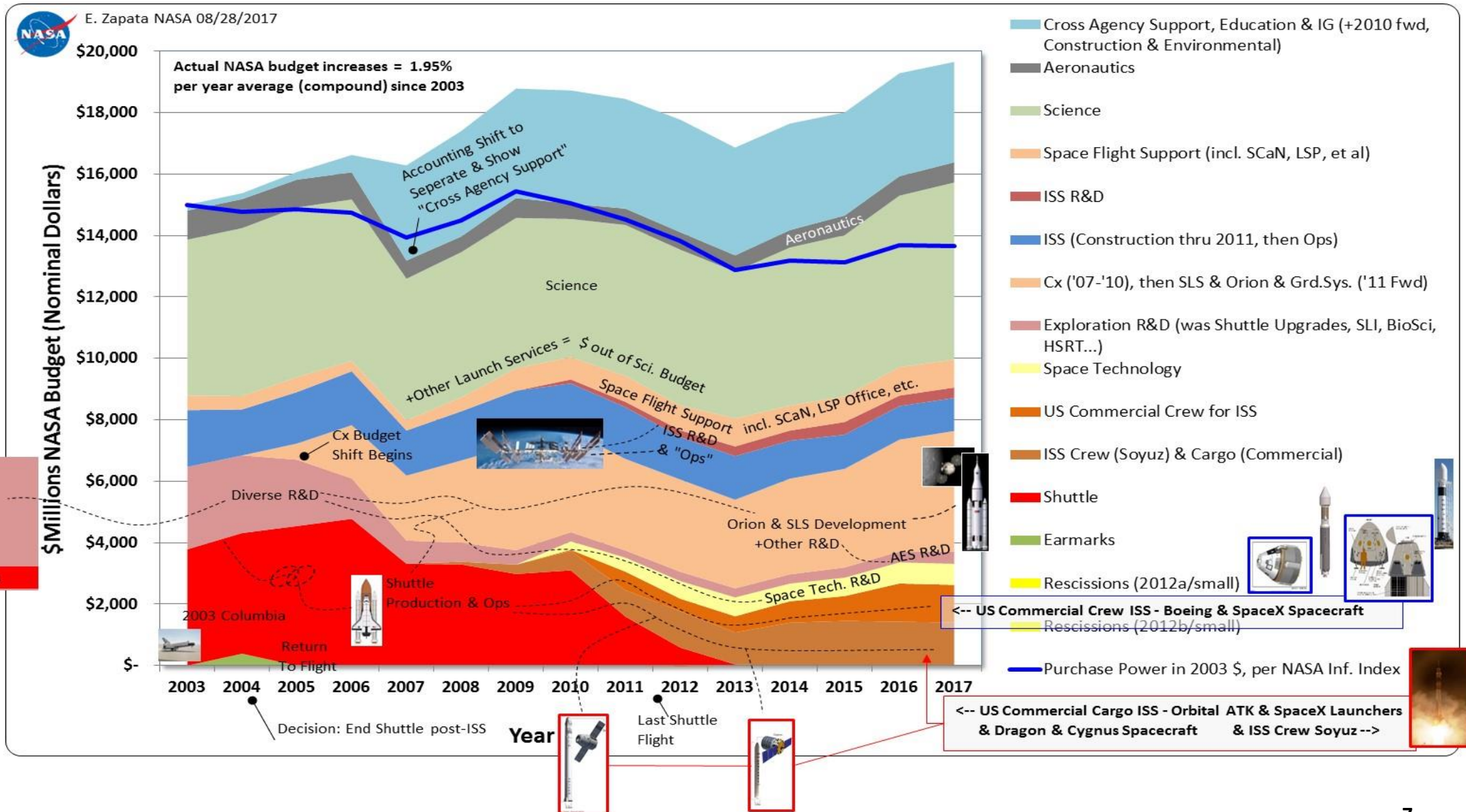
http://www.spacepolicyonline.com/news/senate-appropriators-approve-19-3-billion-for-nasa-for-fy2017

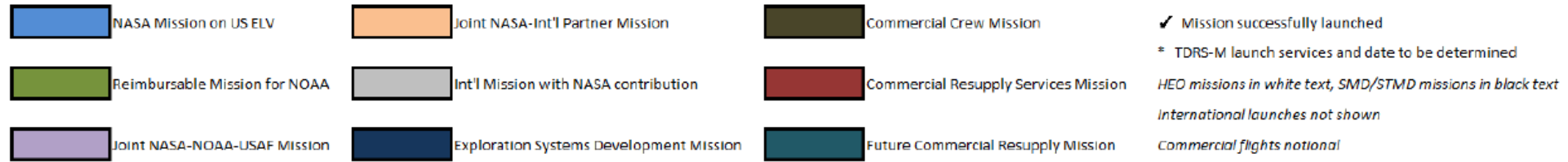
2022 - 2023 use same as 2021, but with average 2003 to date historical budget increases of 1.95% above 2021.

2. Removed 12% (estimated) from the above budget data for government management. (The model adds this back in separately).

i.e., Orion Development Sum Procurement \$ ONLY remaining to completion, 2016 to 2023, in 2017 \$ as shown.

The NASA Budget – Purchase Power Drop Since 2003 = 9%






As of 10/30/2017
23 US Major
Launches in 2017

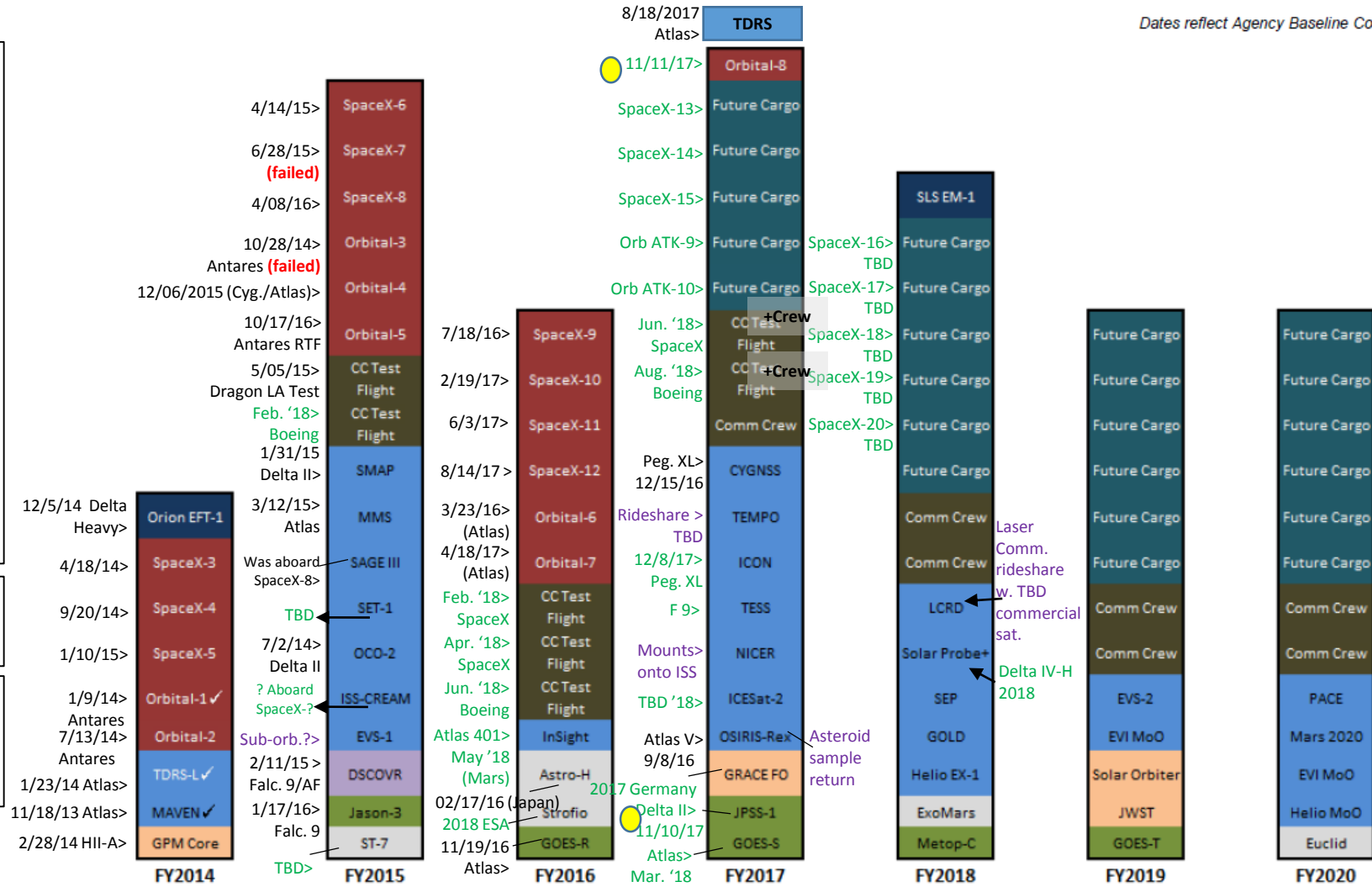
6 Atlas (4 DoD, 1 NASA, 1 ISS cargo,
0 commercial, 0 NOAA)
1 Delta IV (1 DoD)
0 Delta II (0 NASA)

16 Falcon 9 (11 commercial, 3 ISS cargo, 0 NASA, 2 DoD)
Landing Success / Attempts
% Sea / %Land / %Average
71% / 100% / 79%

+1 Minotaur (small, DoD)

Black = Actual
Green = Planned
 = Next

**1st Falcon Heavy
Flight Demo
TBD 2017**



1st SLS
Flight Demo
TBD 2019

<https://spaceflightnow.com/2017/04/28/nasa-confirms-first-flight-of-space-launch-system-will-slip-to-2019/>

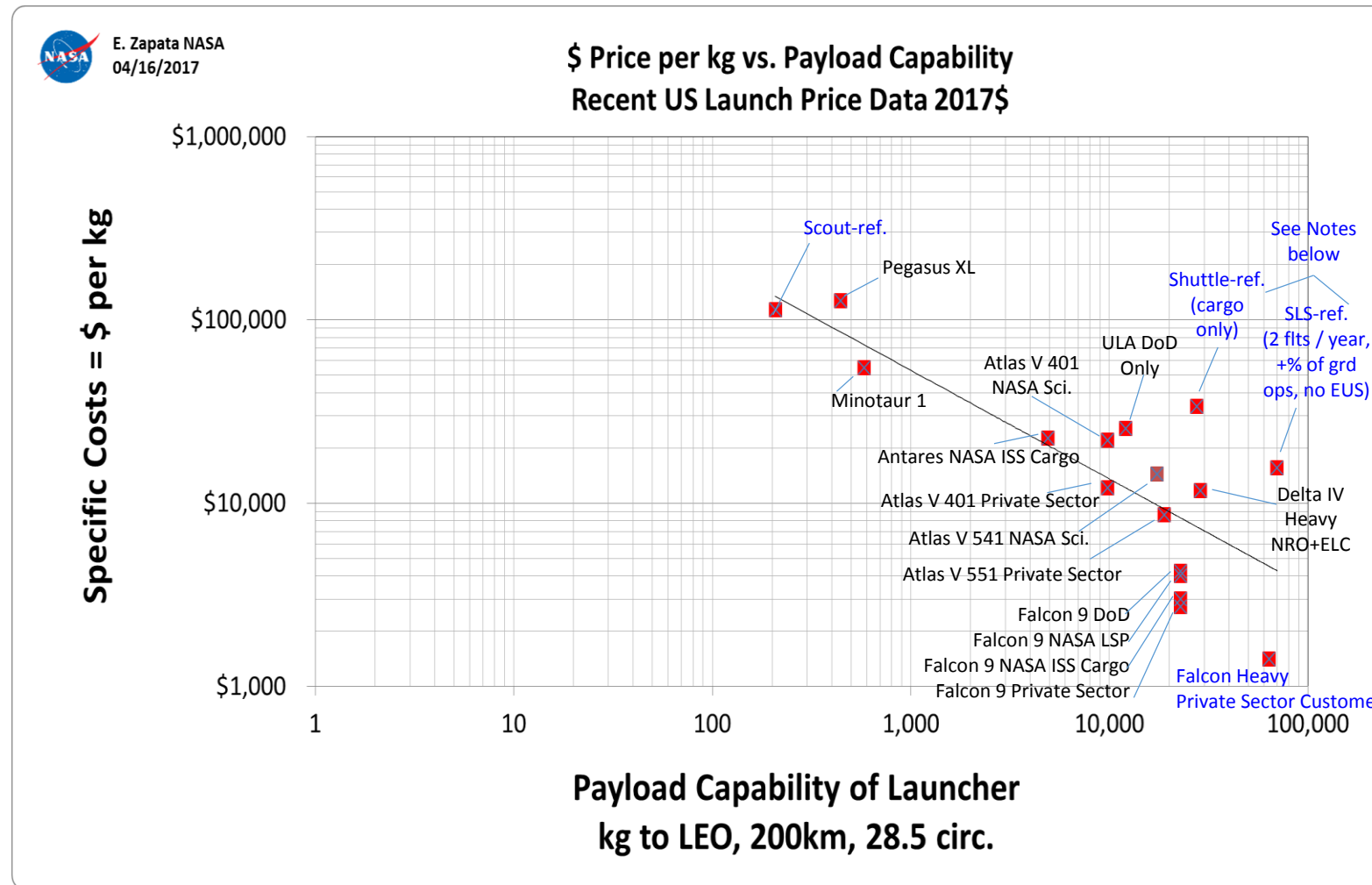
“The uncrewed Orion will travel into Distant Retrograde Orbit, breaking the distance record reached by the most remote Apollo spacecraft, and then 30,000 miles farther out (275,000 total miles). The mission will last 22 days and will test system readiness for future crewed operations.”

-as of 4/9/2016
<http://www.nasa.gov/exploration/systems/>

Original planning chart from:
508_CFO_presentation.pdf, March 2014 ->
https://www.nasa.gov/sites/default/files/files/508_CFO_presentation.pdf

Recent Launch Prices as \$/kg of Payload (2017\$)

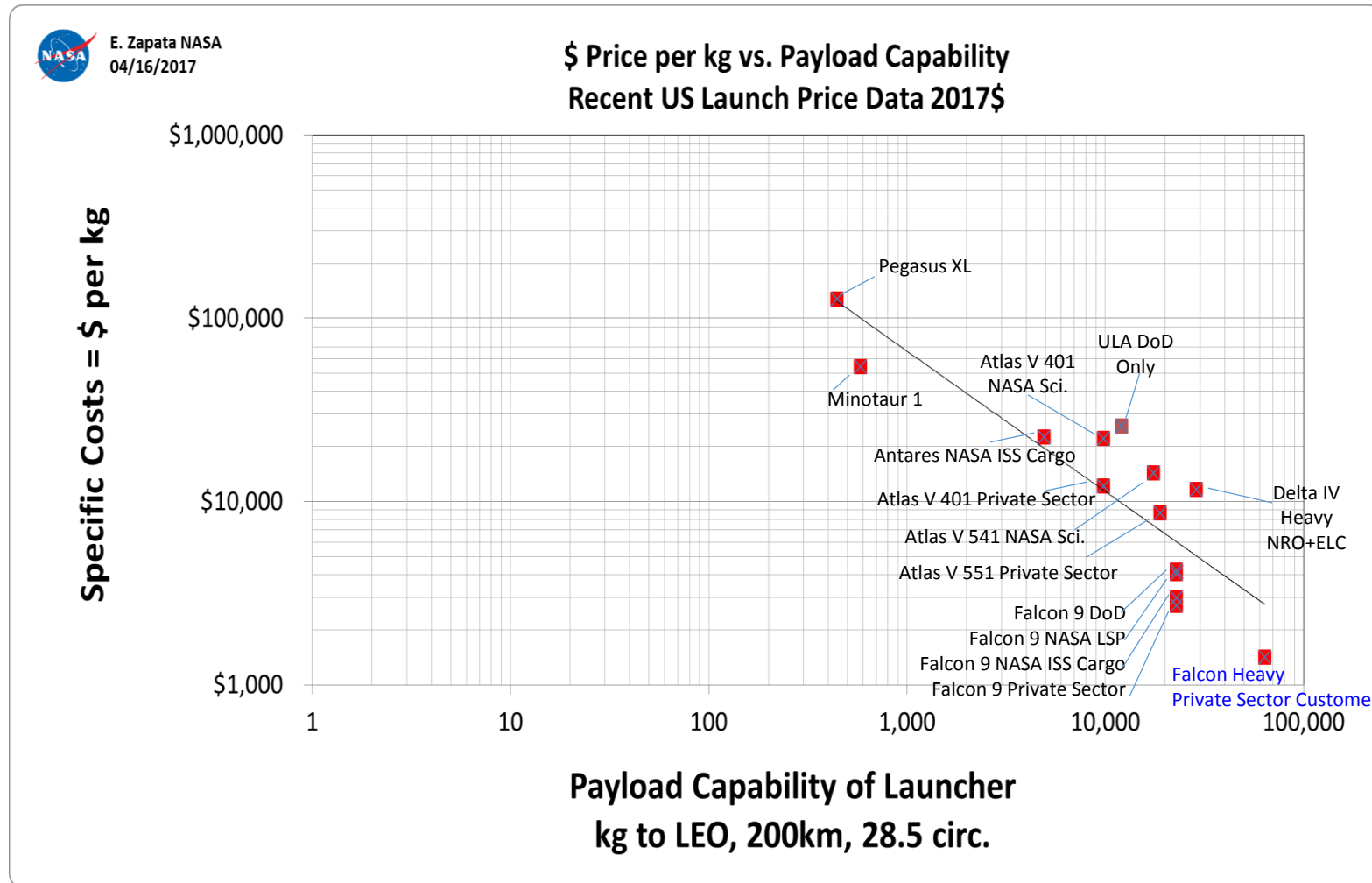
US Medium Launch + Scout, Shuttle, SLS, Falcon Heavy



- The line is a power curve fit ONLY to the points indicated with->
- For NASA and DoD, data are prices to the government, that is procurement costs only, excluding government management, personnel and related.
- For the Space Shuttle, to give a more consistent CARGO comparison, total recurring costs from life cycle cost data (1983-2013) were adjusted to remove crew at a Soyuz price rate, NASA management (civil service) and related were removed to leave procurement dollars only, and R&D years 1981-1982 were excluded as non-operational. Similarly, for SLS the NASA management (personnel) and related costs are also excluded, but unlike Shuttle, ground ops are excluded.

Recent Launch Prices as \$/kg of Payload (2017\$)

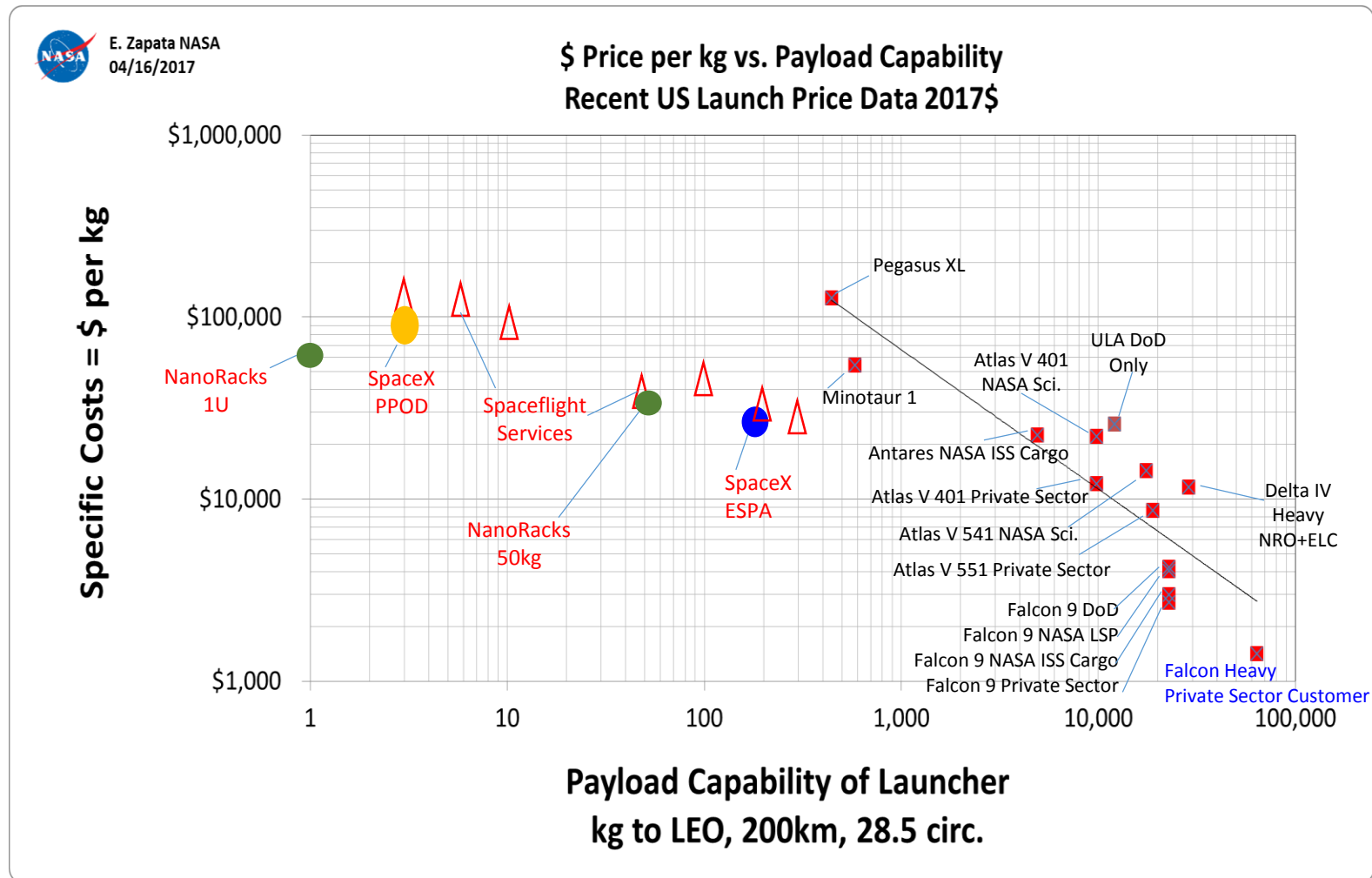
US Medium Launch - NO Scout, Shuttle, SLS



Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services

- NanoRacks as of 12/7/2015
- △ SpaceFlight Services as of 12/7/2015
- See Backup slides for data sources



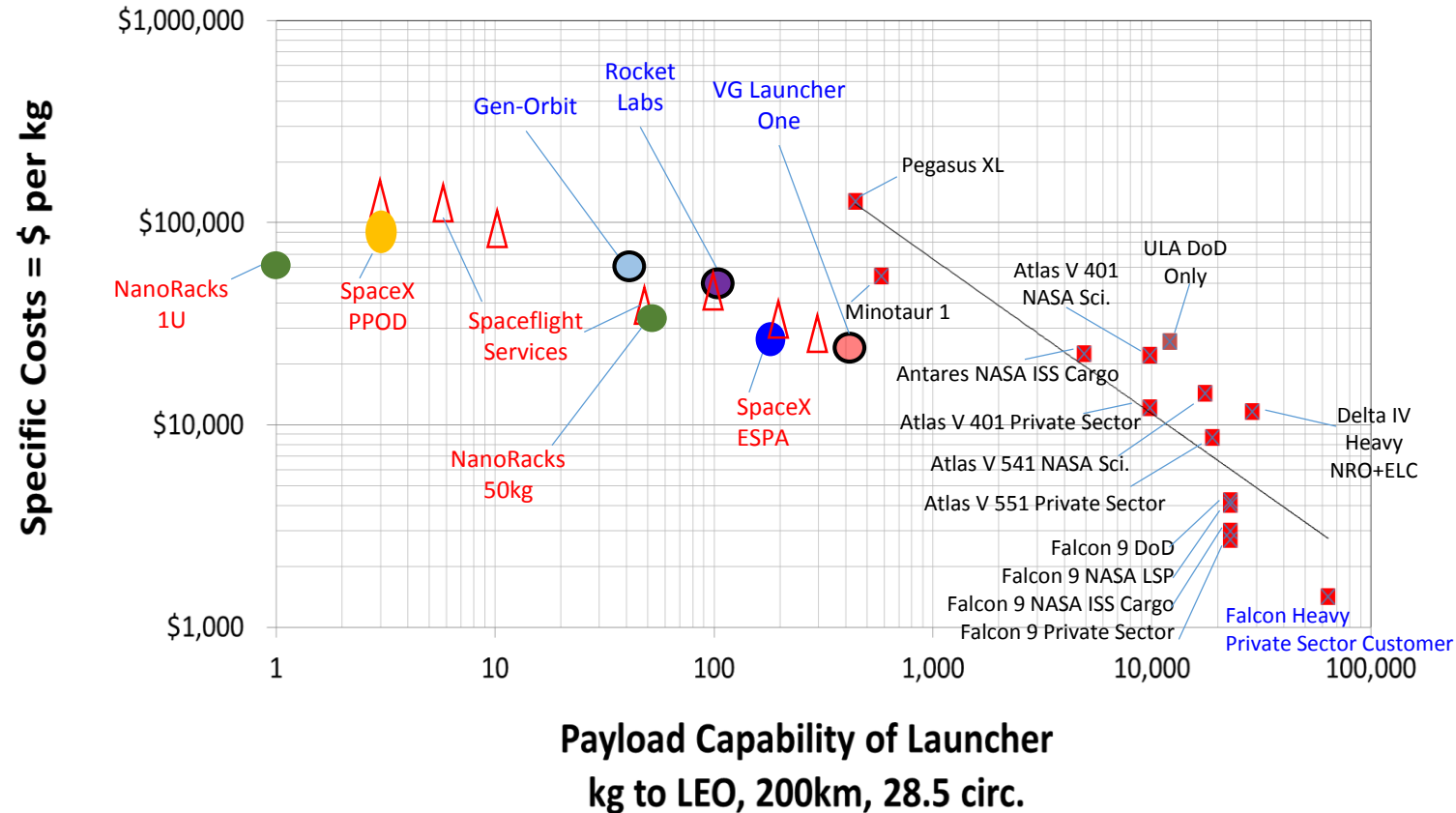
Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services + Some In Development

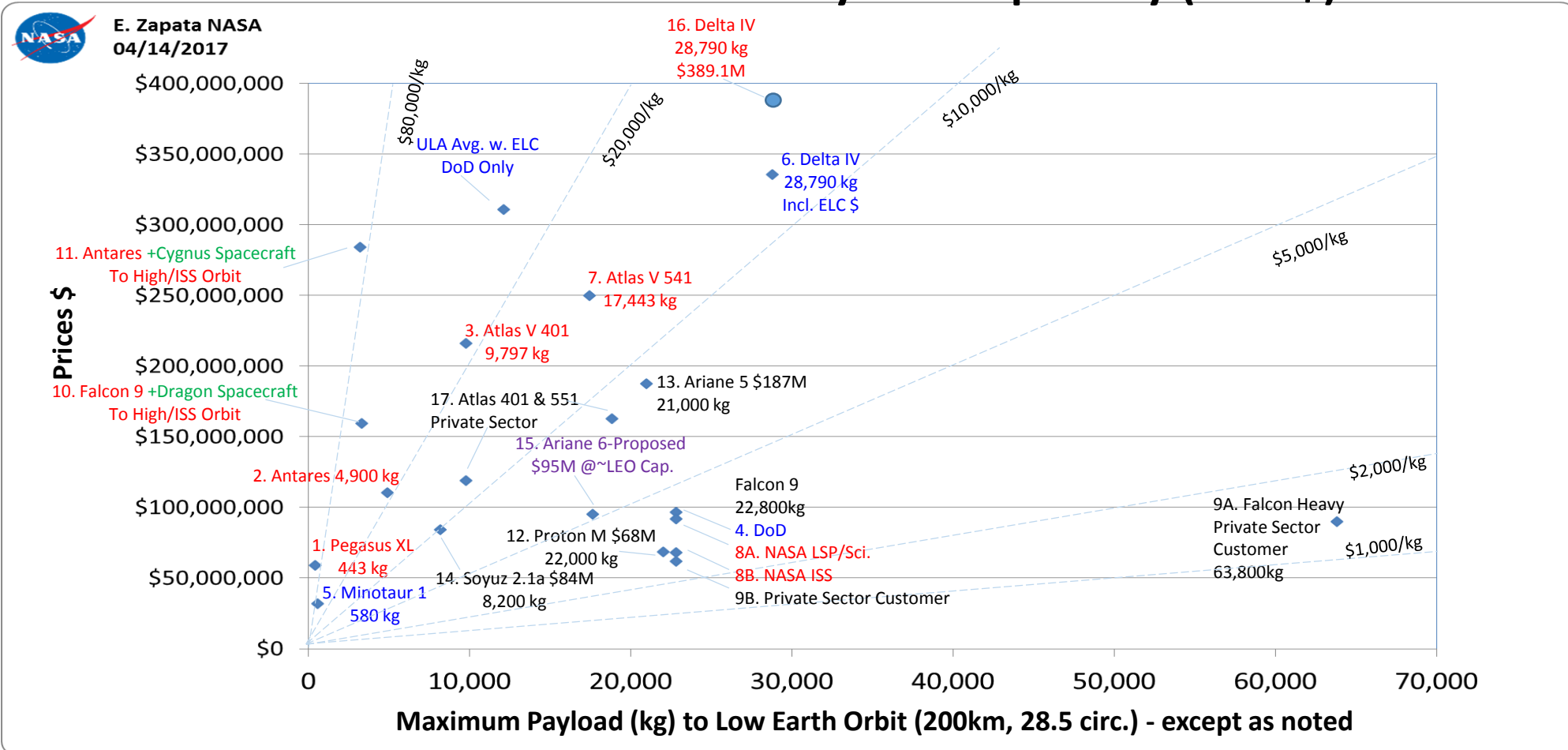
- NanoRacks as of 12/7/2015
- △ SpaceFlight Services as of 12/7/2015
- Virgin Galactic Launcher One as of 9/14/2015
- Rocket Labs as of 8/10/2015
- Generation Orbit as of 6/5/2015
- See Backup slides for data sources

NASA
E. Zapata NASA
04/16/2017

\$ Price per kg vs. Payload Capability
Recent US Launch Price Data 2017\$



Recent Launch Prices vs. Payload Capability (2017\$)



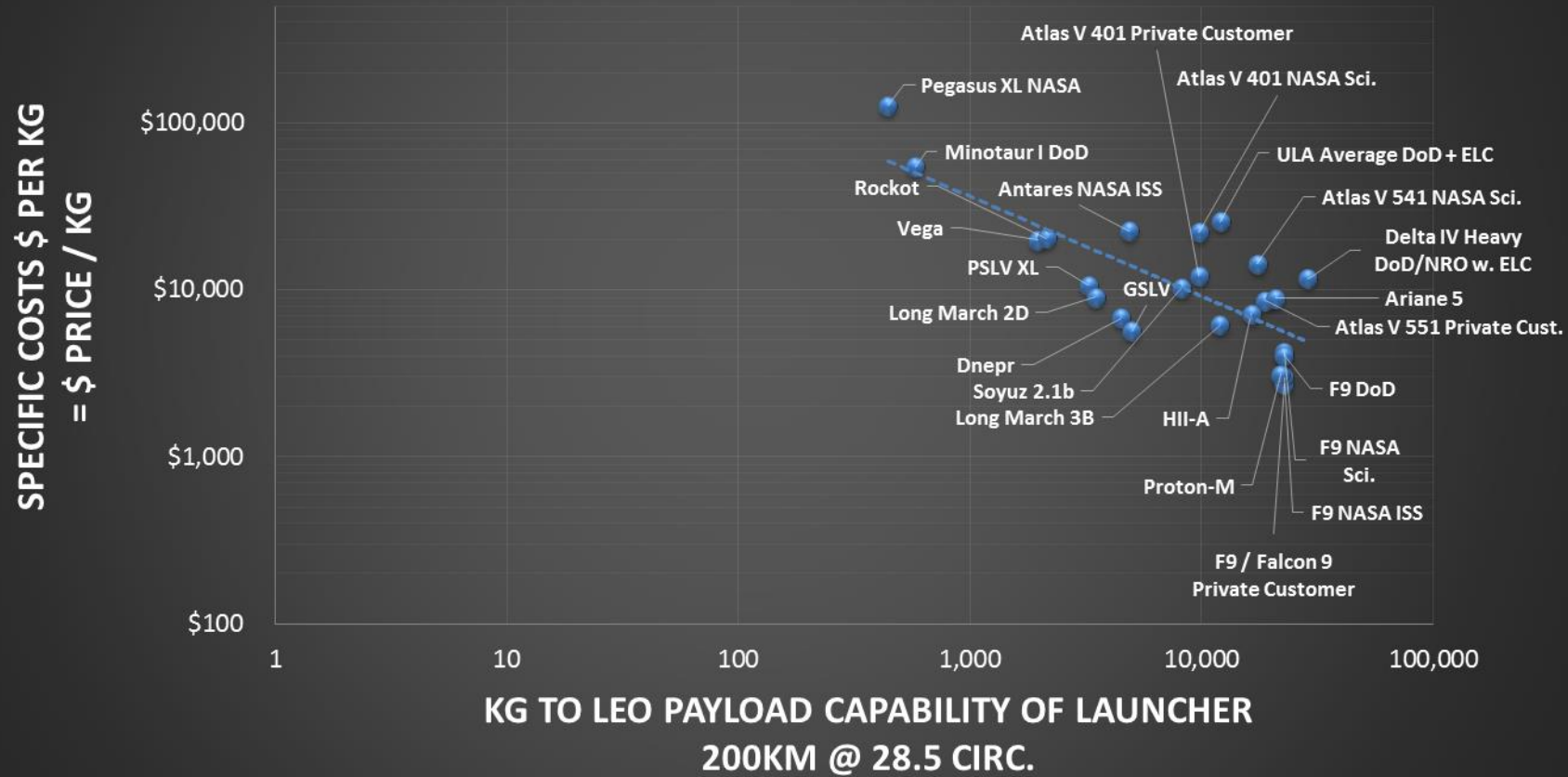
1. NASA price contracted for one 2017 launch (ICON)
2. NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Cygnus Spacecraft)
3. NASA price contracted in 2010, launched in 2013 (MAVEN)
4. DoD Price contracted in 2017 for a GPS launch
5. DoD Price contracted, launched in 2013
6. Price to DoD of the launch service including the amortized EELV Launch Capabilities (ELC) contract, the yearly ELC contract amount divided evenly over the DoD only launches, for NRO
7. NASA Price contracted in 2012, each, with two launches procured together, launched in 2016 + TBD 2017
- 8A. and 8B. NASA Sci. price (8A) contracted in 2012, launched in 2016 (JASON), and (8B) NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Dragon Spacecraft)
- 9A. and 9B. Prices for private sector customers

10. Price to NASA; higher orbit, plus includes providing the Dragon spacecraft for carrying / placing the customers cargo (pressurized, unpressurized, return, etc.)
11. Price to NASA; higher orbit, plus includes providing the Cygnus spacecraft for carrying / placing the customers cargo (pressurized, disposal, etc.)
12. 13. and 14. Prices to customers from 2015 launches in the 2016 FAA launch compendium
15. Ariane 6 –Proposed, shown w. derived equivalent LEO payload capacity. See backup slide and -> <http://www.spaceflightnow.com/news/n1406/17airbussafran/>
16. NASA price contracted in 2015 for one 2018 launch. See backup slide.
17. Per ULA -> www.RocketBuilder.com

Global Views

E. Zapata NASA
04/12/2017

\$ per Kg (2017\$) Existing Capability



Global Views

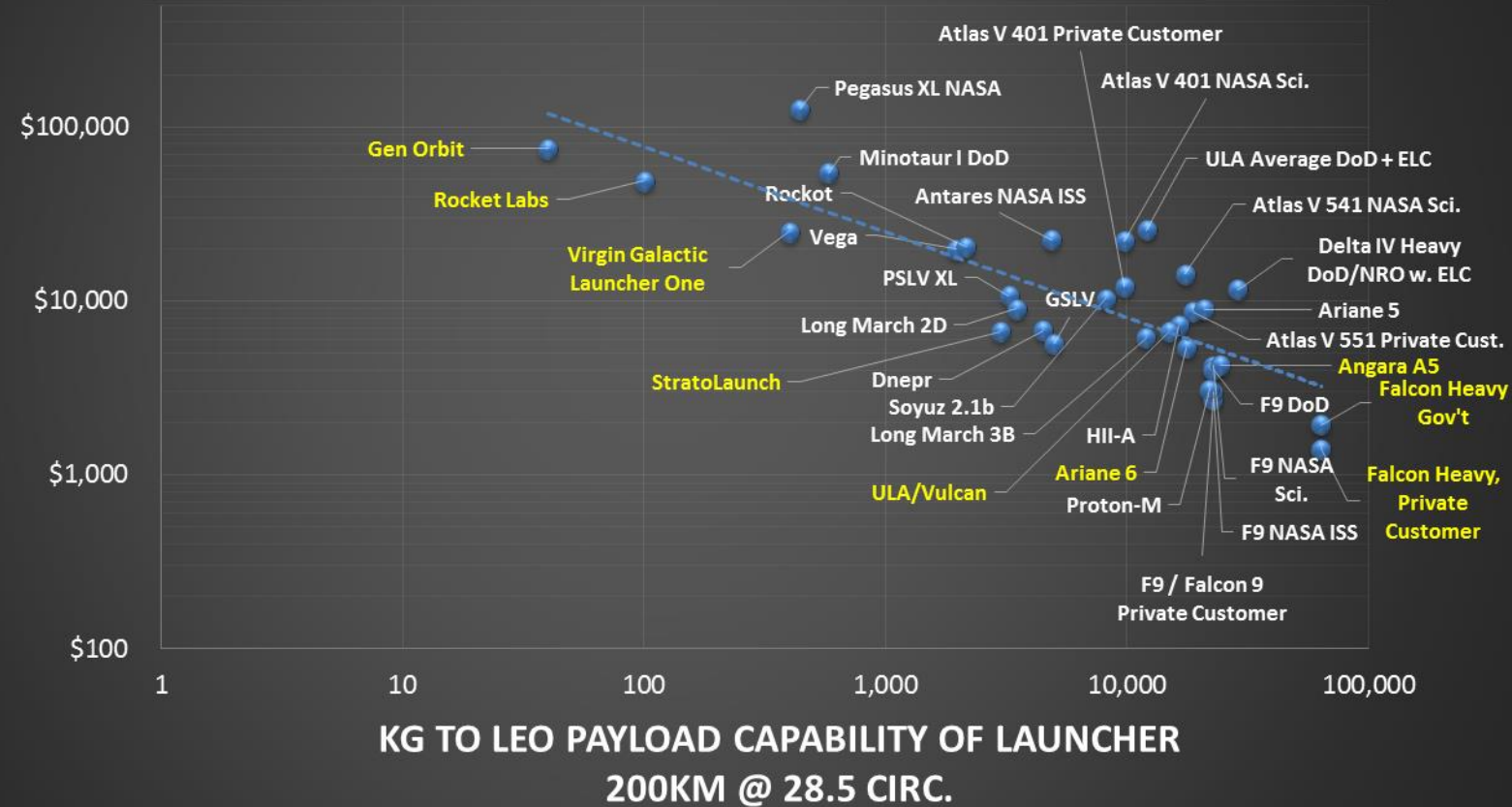


E. Zapata NASA
04/12/2017

\$ per Kg (2017\$) Existing Capability & Planned

Note: Proton-M and GSLV data point uncertainty high. Minotaur I data point is old, 2013. Pegasus has no announced customers after NASA in 2017. "Planned" data points are from specific company statements, but StratoLaunch, ULA/Vulcan and Angara A5 data points are derived, from less specific company statements. Falcon Heavy Gov't is estimated based on Falcon 9 Gov't price percentages above private sector price.

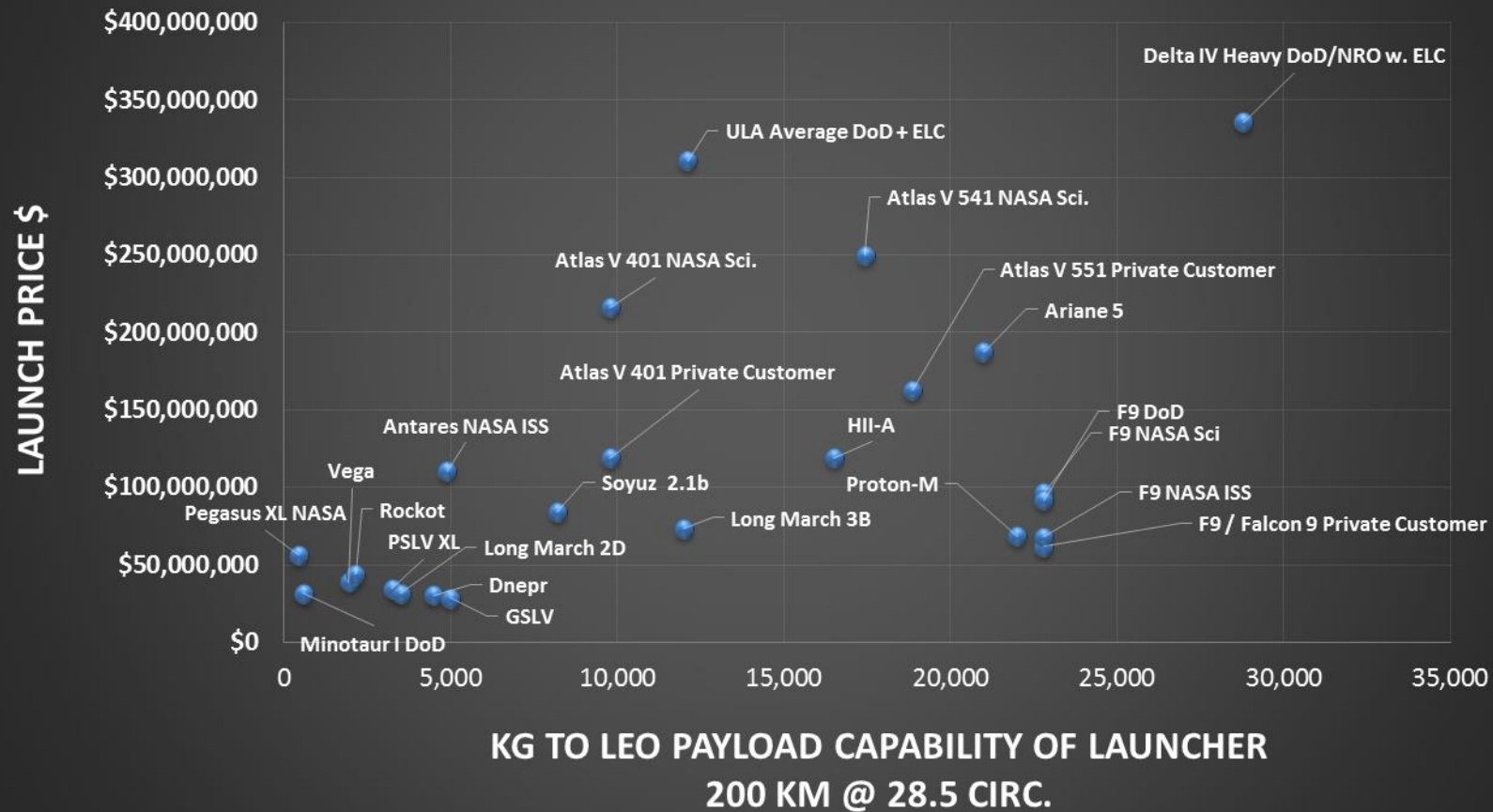
SPECIFIC COSTS \$ PER KG
= \$ PRICE / KG

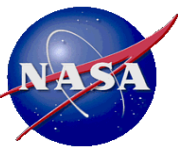


Global Views

E. Zapata NASA
 04/12/2016

Launch Prices Existing Capabilities (2017 \$)





Global Views

SLS (procurement \$ only, no upper stage, + a percent of ground ops \$, no flight ops \$, IF 2 flights per year)

70,000kg->LEO

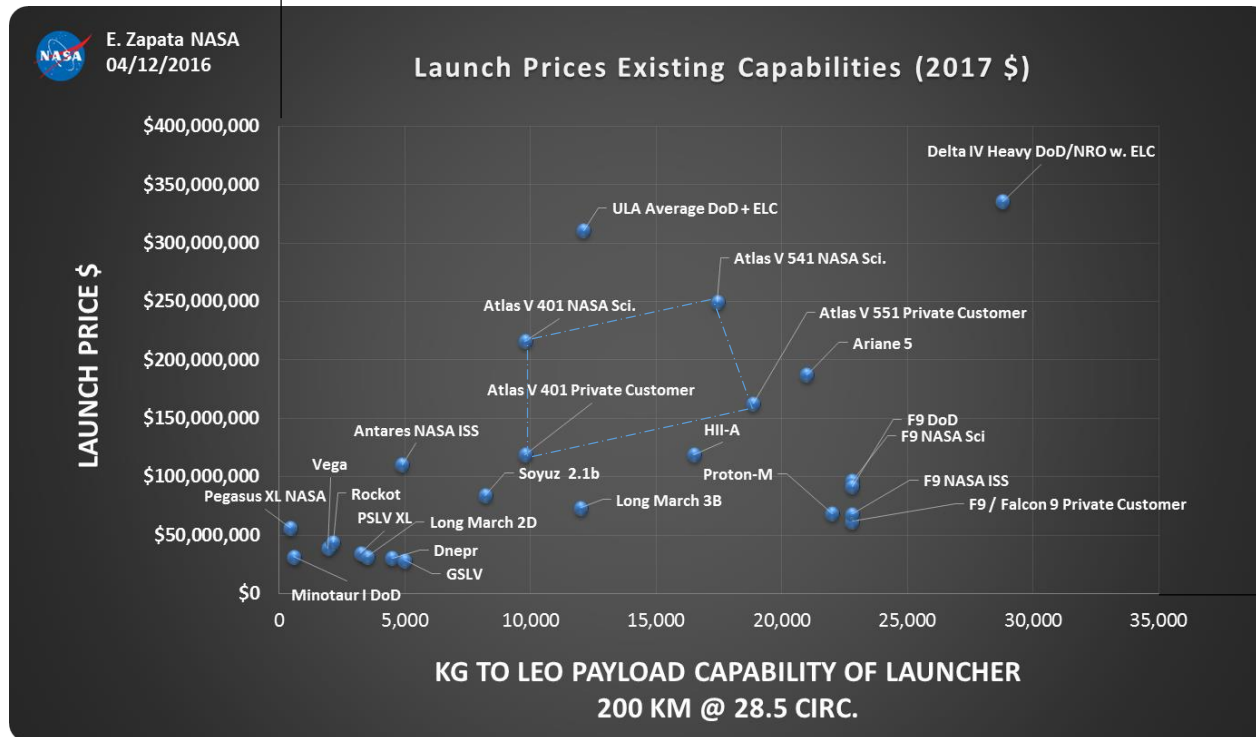
\$1,094,000,000 per Launch

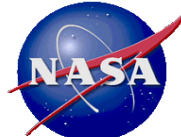
(Add EUS upper stage costs for more capability to ~105t)

Falcon Heavy

63,800 kg->LEO

\$90,000,000 Price to Private Customer





Note!

Launch Systems – Multiple Measures – Especially kg per Year

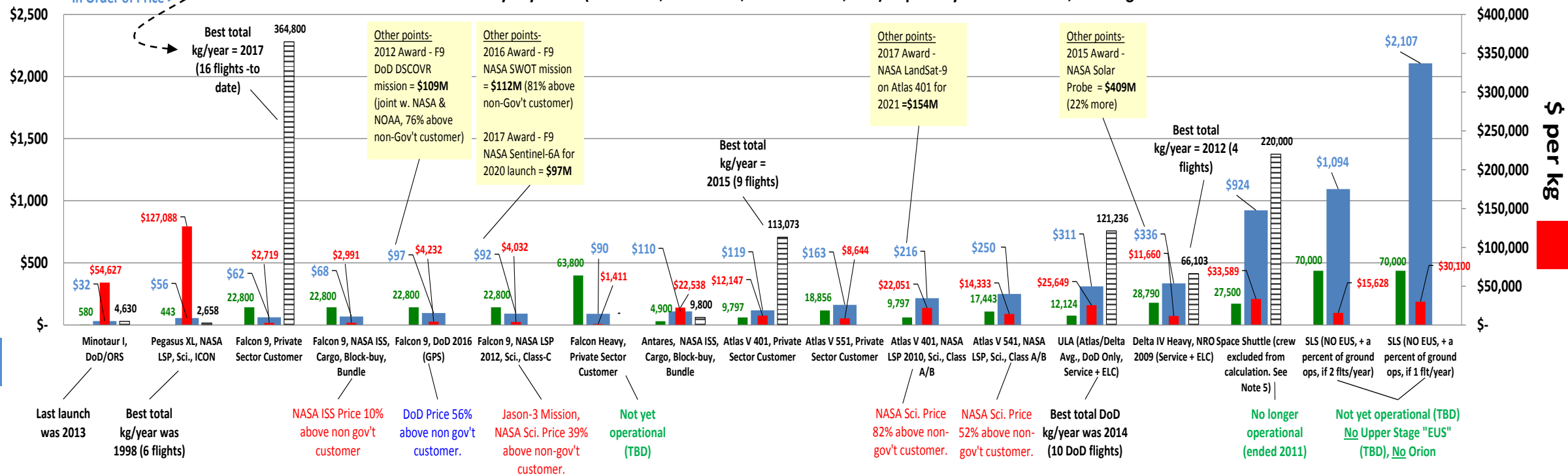


E. Zapata NASA
10/30/2017

- Cost of Entry = Price of the Specific Launcher for that Customer / Application
- Maximum Payload Capability of Launcher, kg to LEO, 200km/28.5 circ. (regardless of actual kg used by customer)
- \$ per kg
- Best Recent Yearly "System" (All Atlas's, All Delta's, All Falcon 9's, etc.) Capability Demonstrated, Total kg to LEO in a Year

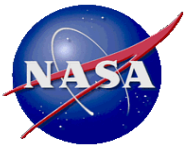
Minimum Cost of Entry \$ M

RECENT DATA 2008 to date in 2017\$
In Order of Price >



Trying to estimate a launch price, the cost of a launch for NASA or DoD? Ask the following, then see which data point above is most similar.

1. Who is procuring the launch?
The NASA Launch Services Program? The NASA ISS Transportation Office (Cargo)? The NASA ISS Commercial Crew Office? The DoD / Air Force? The DoD / Air Force for the National Reconnaissance Office (NRO)? A private sector customer?
2. How is the launch procured? As a block of launches, or as a single award unrelated to others? As a service (like cargo to the ISS)?
3. With what other items is the launcher being procured alongside, such as a spacecraft (Cygnus, Dragon)?
4. What is being launched? Is the launch for simpler cargo, repetitive and similar, or more complex, irreplaceable, unique? Or is it for crew?



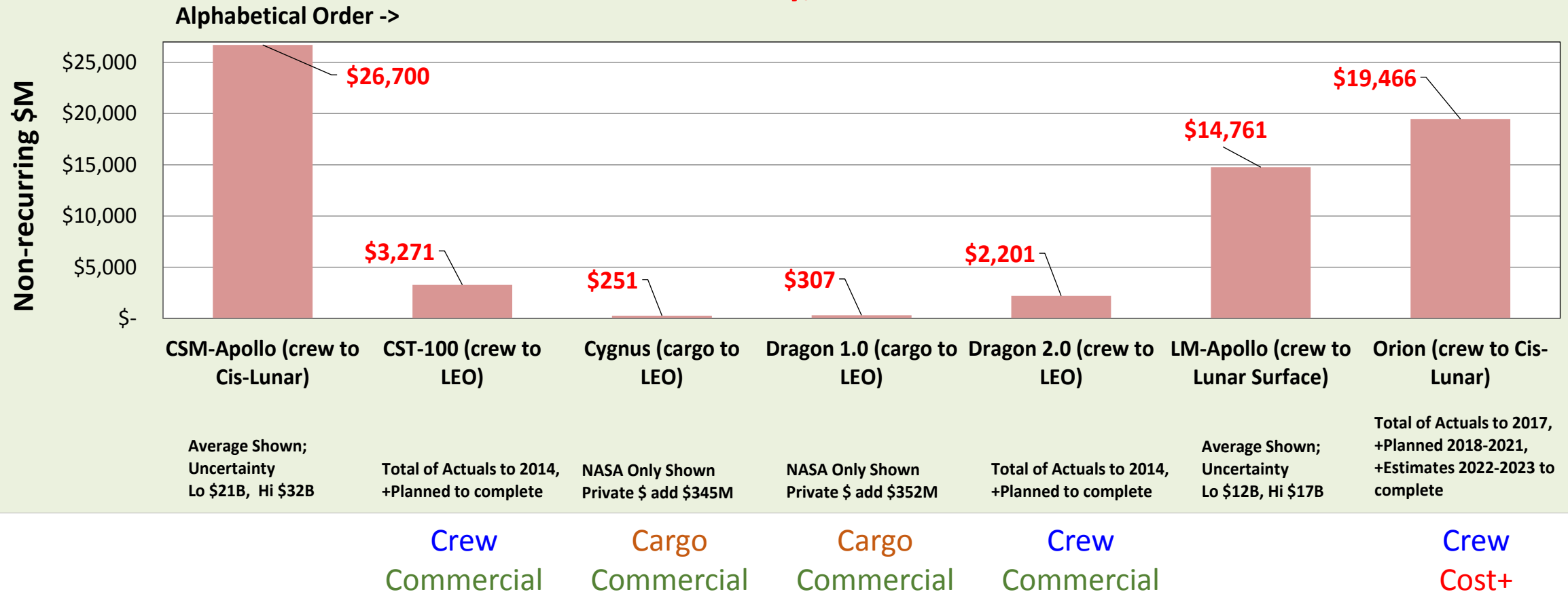
Spacecraft Costs – Development

(Costs = Price to NASA)



E. Zapata NASA
6/2/2017

Spacecraft Non-recurring NASA Development,
Procurement Only, \$M 2017\$





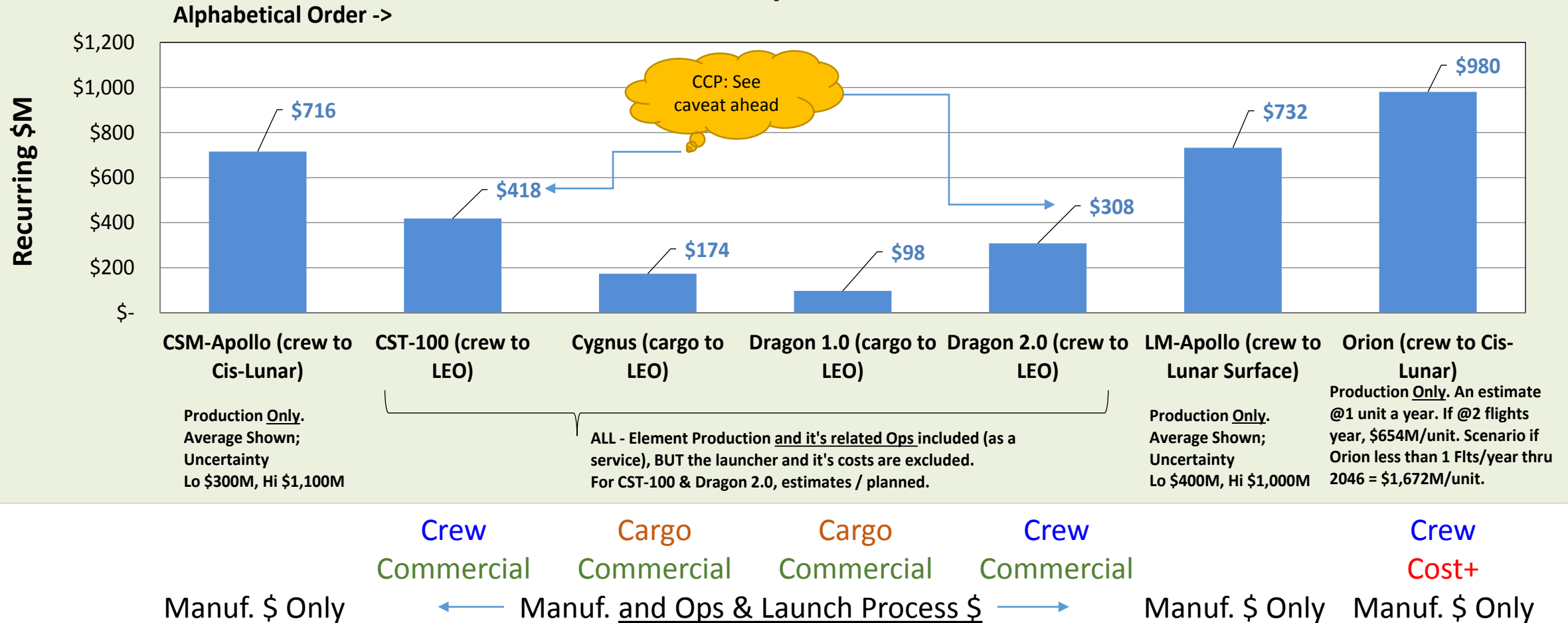
Spacecraft Costs – Per Unit – \$ Thru Delivery Point as Indicated

(Costs = Price to NASA)




E. Zapata NASA
5/8/2017

Spacecraft Recurring Price to NASA per Unit, Procurement Only, \$M 2017\$



Uncertainties, Programs Still in Development

- Future budgets in public documents are often “notional”
 - They may go UP or DOWN
- Example
 - Prior Commercial Crew Recurring Price (by 2020) is based heavily (with adjustments) on FY 16 notional public budget
 - https://www.nasa.gov/sites/default/files/atoms/files/fy2016_budget_book_508_tagged_0.pdf
 - The FY 18 notional public budgets are much **LOWER** by 2020 (operational)
 - https://www.nasa.gov/sites/default/files/atoms/files/fy_2018_budget_estimates.pdf
- Other programs show **INCREASES** in 2018 notional public budget out to 2020 (development) vs. prior years



Fiscal Year				
	2017	2018	2019	2020
t	4,493.3	4,388.7	4,364.7	4,305.4

Cost data updates are a continuous process

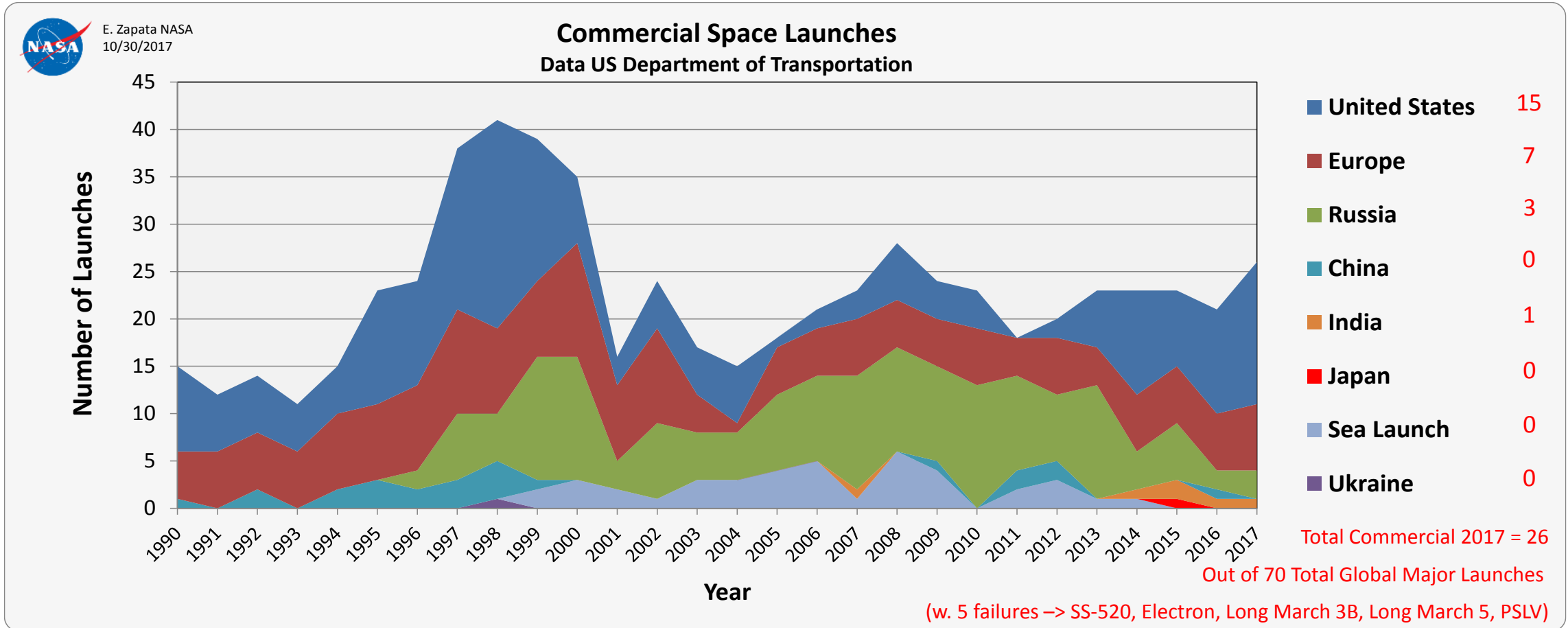
especially until programs complete development and regular operations begin

Competitiveness

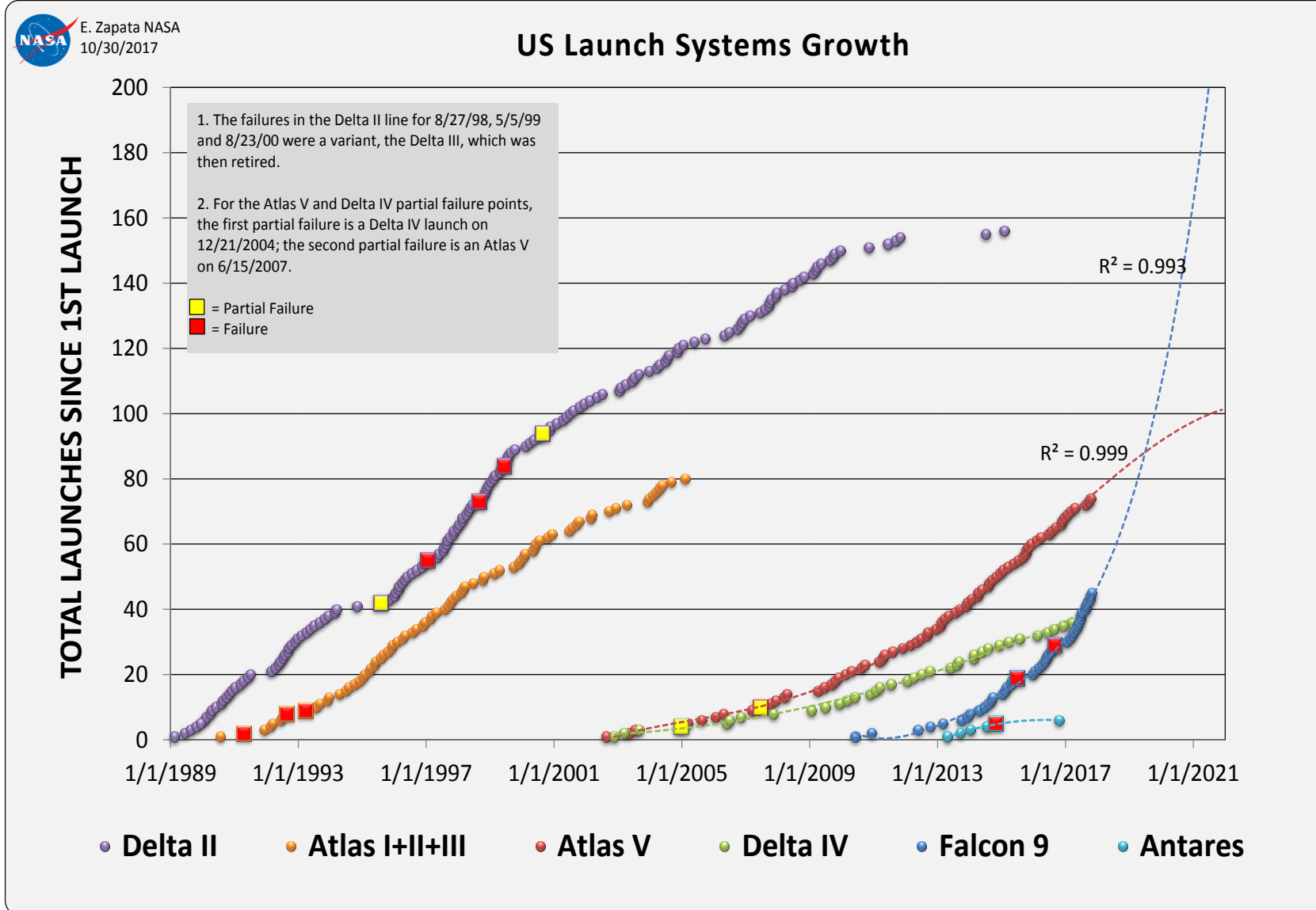
Commercial launch data through 2014 from US DOT <http://www.rita.dot.gov/bts/node/490911>

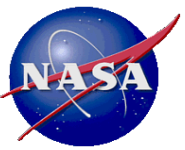
2015 -2017 data from assorted sources

Total global major launch count and failures from <http://www.spacelaunchreport.com/log2017.html#stats>



Growth



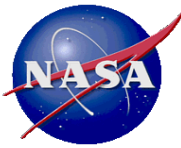


Closing

- Space is hard
- Adding up space system costs, budgets, flights, payload capabilities, etc. – not hard, just tedious
 - Define competitiveness, compare systems, understand cost vs. productivity
 - Establish facts on the ground
- **Value: situational awareness**
 - **Where are we?**
 - **Where might we go?**

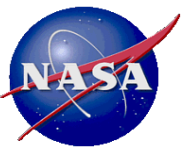
Questions?

Backup



Data Sources, Small Payload Launch Options, Small Launch in Development, Other (see slides 6-7)

- As of 12/07/2015 - NanoRacks - “Commercial payloads start at \$60,000 per 1U” + volume discounts, to 50kg as advertised @ <http://nanoracks.com/resources/faq/>
 - 3U \$295,000, 6U \$545,000, 12U \$995,000, 50kg \$1,750,000, 100kg \$3,950,000, 200kg \$5,950,000, 300kg \$7,950,000 as advertised @ <http://www.spaceflightindustries.com/schedule-pricing/>
- SpaceX - secondary payload “PPOD” to LEO \$200,000-\$325,000 (=\$67,000-\$108,000/kg; from Aug. 2012, 26th Annual AIAA USU, Conference on Small Satellites)
- SpaceX – secondary payload, ESPA-class satellite weighing up to 180 kilograms would cost \$4–5 million for LEO; from August 2012, 26th Annual AIAA USU, Conference on Small Satellites (=\$22,000 to \$28,000/kg)
- As of 09/14/2015 – Virgin / Launcher One - **In development** - 400kg to LEO for \$10M (=\$25,000/kg) per <http://www.parabolicarc.com/2015/09/14/virgin-galactic-announces-capable-launcherone/>
- As of 08/10/2015 - Rocket Lab - **In development** - 100kg to LEO for \$4.9M (=\$49,000/kg) per <http://www.geekwire.com/2015/reserve-a-launch-for-your-satellite-online-rocket-lab-can-make-it-so/> albeit to a 310 mile high orbit, implying performance to LEO 200nm is more, so the “ ”
- As of 06/05/2015 - Generation Orbit - **In development** – 40kg to LEO for \$2.5M (=\$62,500/kg) per <http://www.satellitetoday.com/launch/2015/06/05/generation-orbit-gains-golauncher2-commitments-plans-golauncher-3/>
- As of 07/08/2016 – Stratolaunch / Vulcan Aerospace – **In development** – No public price statements by the company. Some early payload performance statements (6,100kg to LEO) that have since been overtaken by events. https://en.wikipedia.org/wiki/Stratolaunch_Systems



Misc.

Ariane 6 in the news:

July 2, 2014

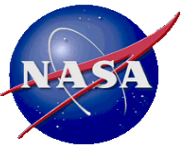
Airbus Defends Springing Last-minute Ariane 6 Design on ESA

“PARIS — The head of Airbus’ space division on July 1 said his company was forced to come up with an Ariane 6 rocket design that competed with the version approved by the European and French space agencies **because the agency version ultimately would have decimated Europe’s rocket industry.**

Testifying before the French Senate Committee on Foreign Affairs, Defense and Armed Forces, Francois Auque said the solid-fuel-dominated Ariane 6 design that the European Space Agency and the French space agency, CNES, approved in July 2013 would have attracted mainly European government customers — a market whose size would mean reducing Europe’s rocket design and production industry by two-thirds.

To avoid being decimated, he said, European rocket builders needed to be sure that the commercial market, which accounts for 90 percent of the launches of Europe’s current heavy-lift Ariane 5 vehicle, would support the new vehicle.”

<http://www.spacenews.com/article/launch-report/41117airbus-defends-springing-last-minute-ariane-6-design-on-esa>



Misc.

Delta IV Cost (Price) to NASA:

March 18, 2015

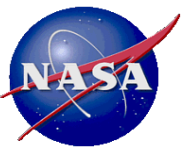
Delta 4-Heavy Selected for Launch of Solar Probe

“As expected, NASA announced its selection of the United Launch Alliance Delta 4-Heavy rocket to dispatch the Solar Probe Plus mission from Earth. Liftoff from Cape Canaveral is set for July 31, 2018, at the opening of a 20-day launch window, NASA said in a press release.

...

The launch contract’s value is \$389.1 million, according to NASA.”

<http://spaceflightnow.com/2015/03/18/delta-4-heavy-selected-for-launch-of-solar-probe/>



Misc.

Falcon 9 Cost (Price) to NASA:

November 22, 2016

NASA Selects Launch Services for Global Surface Water Survey Mission

“NASA has selected Space Exploration Technologies (SpaceX) of Hawthorne, California, to provide launch services for the agency’s Surface Water and Ocean Topography ([SWOT](#)) mission. Launch is targeted for April 2021 on a SpaceX Falcon 9 rocket from Space Launch Complex 4E at Vandenberg Air Force Base in California.

The total cost for NASA to launch SWOT is approximately \$112 million.”

<https://www.nasa.gov/press-release/nasa-selects-launch-services-for-global-surface-water-survey-mission>